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Photothermal probing of metallic nanoparticles on nanomechanical string resonators to study plasmonic heating effects

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When irradiated with light from the visible or near-infrared spectral region, sub-wavelength metal nanoparticles, usually nano-sized silver or gold, exhibit localized surface plasmon resonance (LSPRs). Plasmonic nanostructures are essential in a variety of applications e.g. surface-enhanced Raman spectroscopy [1], utilized as confined heat sources for cancer treatment [2] or surface enhanced infrared absorption spectroscopy [3]. However, there is still a lack of accurate and reliable measurement techniques for recording heating generated by electromagnetic hot spots e.g. plasmonic nanoparticle dimers.

Recently, the ultra-high temperature sensitivity of SiN nanomechanical string resonators has been exploited in their use as a robust analysis tool for low-power investigation of thermoplasmonic effects in single Au nanostructures [4]. Herein, we utilize SiN nanomechanical string resonators (Fig. 1(a)) for studying heat generated by ~200 nm in diameter Au nanoparticle dimers. First, Au nanoparticles were sprayed on the SiN string using nebulizer. The Au interparticle distances were adjusted to >5µm, and then the structures were imaged using Scanning Electron Microscopy (SEM) and dark-field scattering microscopy for identifying single, nearly touching Au particle dimers, see (Fig. 1). The same Au dimers (Fig.1 (b)) were probed using a laser-Doppler vibrometer (MSA-500 from Polytec GmbH). The temperature induced localized resonance frequency detuning in the SiN string as a result of heating was recorded and subsequently mapped for both s- and p-polarizations (Fig. 2 (b)) of incident laser from the vibrometer.

The localized heating in the SiN string when the laser illuminates the dimer is a combination of heating due to plasmonic effects and absorption by the SiN strings. The laser is partially polarized in a ratio of 4:1. As seen from the FEM simulation (Fig. 2(a)), the ratio of plasmonic heating in the two polarizations is 5:2. Theoretical simulations show that the total heating due to plasmonic effects in both polarization directions is 22:13 (~1.7) (Fig. 2 (c)). Experimentally, the ratio of frequency detuning in both polarizations (Fig. 2 (b)) is around 1.4 (191/137). We find that the theoretical simulations and the experiments are in close agreement. The minor difference can be attributed to:

(i) Imperfect alignment between the laser and the axes of the dimer

(ii) Morphology – The simulation assumes that the nanoparticles have a smooth surface

(iii) SiN strings absorb some of the laser energy

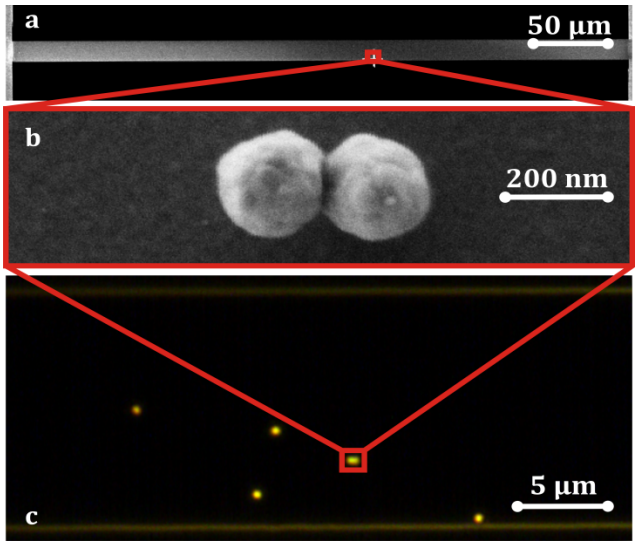

Figure 1 (a) SiN string resonator coated with ~200 nm in diameter single Au nanoparticles and particle dimers. The Au nanoparticles were deposited using nebulizer. The width of the SiN string is 14 µm, thickness is 200 nm and the length is 400 µm. (b) a SEM image of a single Au dimer. (c) The Au nanoparticle dimer (encircled) on a SiN string is imaged using dark-field scattering microscopy.

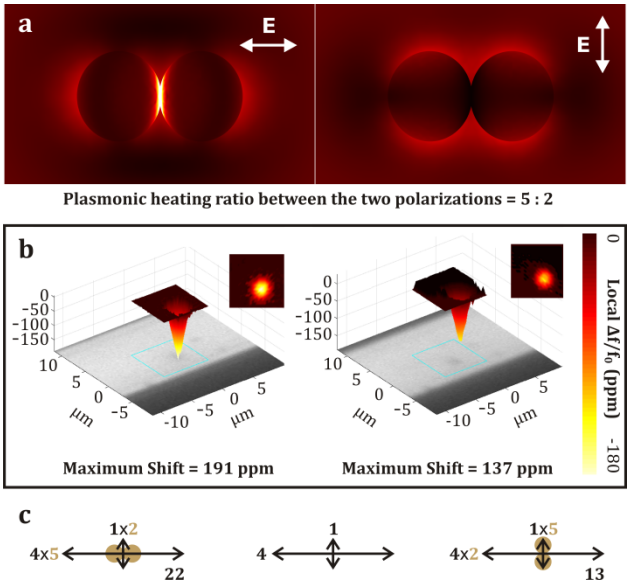

Figure 2 (a) FEM simulation of the electric field enhancement (ranged from 0 to 8) for a silicon nitride string covered by a gold nanoparticle dimer. The dimer consists of two touched gold nanoparticles, each modelled as an ellipsoid with dimensions of ~200 nm according to the SEM image. (Detailed dimensions for the left nanoparticle: length along the dimer axis = 207 nm, width perpendicular to the dimer axis = 224 nm, height = 200 nm; for the right nanoparticle: length = 209 nm, width = 224 nm, height = 200 nm). (b) Photothermal maps of a gold nanoparticle dimer, obtained by scanning using a 633 nm, partially polarized laser with a power ratio of 4:1. The laser is partially polarized along and perpendicular to the dimer axis for the left and right image, separately. The irradiance of the laser is I = 11 µW/µm^2 via a 50x objective. (c) Schematic calculation of the heating ratio between the two polarizations, where the gold nanoparticle dimer is aligned to and perpendicular to the partial polarization direction of the laser respectively.

[1] Sharma, B.; Frontiera, R. R.; Henry, A.-I.; Ringe, E.; Van Duyne, R. P. *Mater. Today*. **2012**, 15, 16-25

[2] Lal, S.; Clare, S. E.; Halas, N. J. *Acc. Chem. Res.* **2008**, 41, 1842-1851

[3] Aroca R.F.; Ross D.J.; Domingo C. *Appl. Spectrosc.* **2004**, 58, 324A–338A

[4] Schmid, S.; Wu, K.; Larsen, P. E.; Rindzevicius, T.; Boisen, A. *Nano Lett.* **2014**,14, 2318−2321